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SOLAR ACTIVITY ASYMMETRIES AND THEIR POSSIBLE EFFECT ON THE HIGH ENERGY COSMIC RAY PERPENDICULAR GRADIENT

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ABSTRACT

The northern solar hemisphere was considerably more active than the southern during the latter portion of sunspot cycle 19 and the first part of cycle 20 in all parameters investigated: solar flare reports, type II radio bursts, sunspot numbers and sunspot areas. Since 1874, sunspot area measurements suggest only one other lengthy time period (1883-1900) when one hemisphere of the sun was persistently more active than the other. For the remaining time periods, the sunspot areas appear to have been approximately equal for each hemisphere. From this we suggest the possibility that the perpendicular cosmic ray gradient inferred between 1959 and 1970 may not be representative of "normal" conditions primarily because solar activity was not evenly distributed between the two hemispheres, and consequently the cosmic ray propagation characteristics may not have been symmetric between the northern and southern portions of the heliosphere.

INTRODUCTION

Several studies /1,2,3,4/ have suggested that a southward pointing gradient existed in the density of high energy cosmic rays in the region of the earth's orbit during the 1960's. There is also some evidence for a possible reversal of this gradient during subsequent years. It appears, however, that the consistent gradient observed throughout the 1960's was not followed by an equally strong gradient in the opposite direction during the 1970's.

Assuming that the galactic cosmic ray intensity is isotropic, asymmetric cosmic ray density gradients cannot be maintained continuously from the northern to the southern boundary of the heliosphere. The gradients must, therefore, be localized within a few AU of the observation point (e.g. the earth), and it should be possible to associate them with other interplanetary or solar phenomena. The cosmic rays concerned have rigidities in the range of a few GV (detected by neutron monitors) to above 100 GV, observed by underground muon detectors. The gyro-radii range up to at least 0.5 AU, and any asymmetric gradients observed thus lie within about an AU of the earth.

The existence of these gradients suggests a hemispheric asymmetry in interplanetary conditions. If, for example, more disturbances are carried radially away from the northern solar hemisphere than from the southern, a southward pointing cosmic ray density gradient would be expected in the region of the heliospheric equatorial plane. Similarly, a northward gradient would result from excess activity south of the equatorial plane. Accordingly, we have reviewed data on the location of various forms of solar activity for as long periods as feasible in order to investigate possible long-lived anisotropies in solar activity.

SOLAR ACTIVITY

Positional solar activity data are available in various forms for over 100 years. Using Greenwich solar data from 1874 to 1954, Newton and Milsom /5/ concluded that the degree of solar activity between the northern and southern solar hemispheres did not appear to depend upon the 22-year solar magnetic cycle. By plotting sunspot area vs. date for each of the solar hemispheres for observations made between 1874 and 1974, White and Trotter /6/ reached a similar conclusion, i.e. that, on average to first order, the solar magnetic cycle was approximately uniform in each solar hemisphere. Their technique, however, was principally aimed at identifying alternations between successive solar cycles. We have re-examined this data set and find two time periods when one hemisphere of the sun appeared to be dominant over periods longer than a solar cycle.

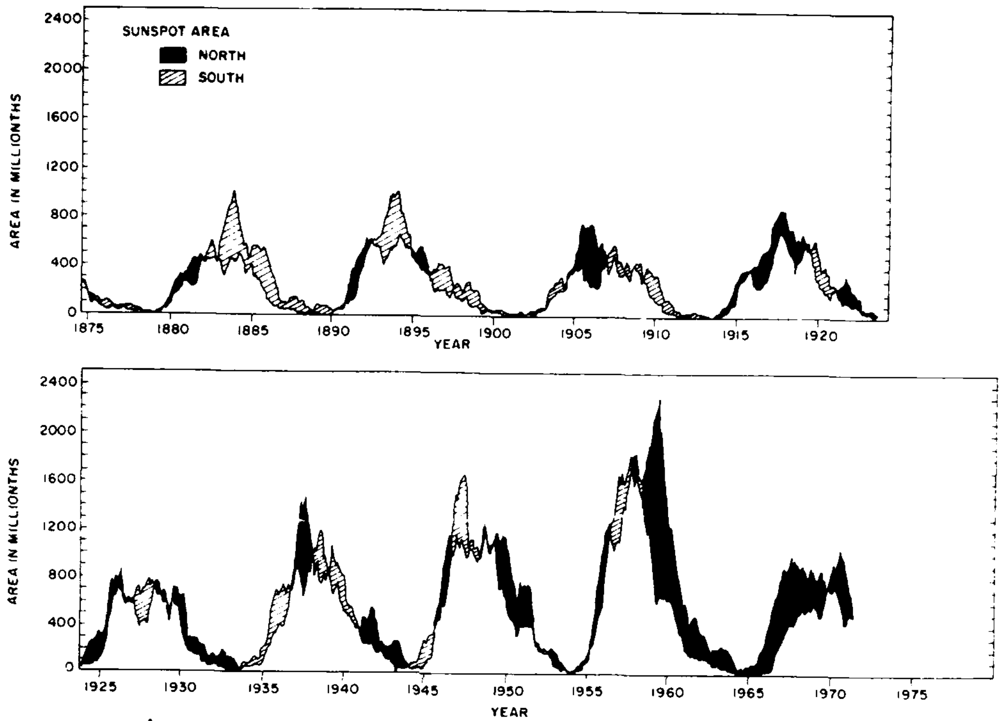

Figure 1. Sunspot areas for north and south hemispheres of the sun between 1873 and 1972. The dark sections between the two lines indicates periods with an excess of sunspot areas in the northern hemisphere of the sun. The cross-hatched sections between the two lines indicates time periods with an excess of sunspots in the southern hemisphere of the sun. (Figure after White and Trotter /6/)

Figure 1 shows the sunspot areas for both hemispheres of the sun from 1874 to 1972. The values plotted were obtained from the White and Trotter publication /6/. They used a running mean of 13 solar rotations. (For an explanation of the input values used by White and Trotter, the reader is referred to their publication.) The figure illustrates an excess of sunspot areas in the southern hemisphere of the sun between 1882 and approximately 1905. Between 1905 and approximately 1948 the sunspot areas appear to be equally divided between the two hemispheres over each solar cycle. From 1948 until 1972 there is an excess of sunspot areas in the northern hemisphere of the sun with a clear dominance between 1958 and 1971 as indicated in Figure 2. Figure 2 also illustrates that northern hemisphere dominance is evident in other measures of solar activity, in this case the number of flares as observed in H-α. Note the clear correspondence for all years but one between the two parameters shown. We attribute the 1976 discrepancy to the small number of active regions occurring during the year, giving the opportunity for a few regions to dominate the flare activity. (A similar relationship is observed between sunspot areas and the occurrence of flares of importance $\geq$ 1.)

In an earlier paper, Swinson et al., /4/ noted the preponderance of "major" flares and type II radio bursts in the northern hemisphere during the 1960's, and indicated that the period corresponded to the interval between successive solar magnetic polarity reversals. At the time of writing of that paper its authors believed that the asymmetric cosmic ray gradient which occurred during the same time interval might have some physical significance associated with the solar magnetic polarity reversals; we are now more inclined to believe it to be coincidental.

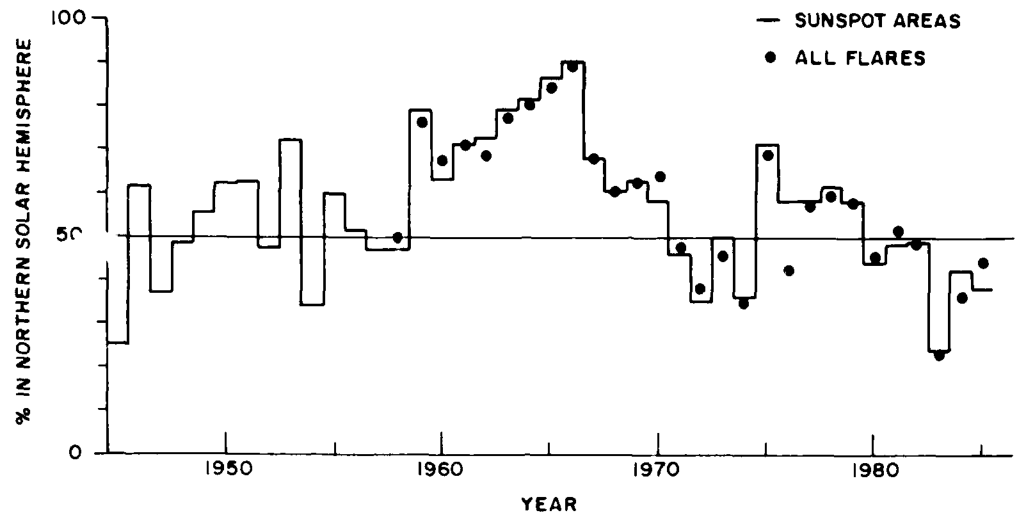

Figure 2. Percentage of sunspot areas (1940-1985) and flares (1958-1985) in the northern hemisphere of the sun.

COSMIC RAY MEASUREMENTS

The investigators listed in the Introduction broadly agree that a southward pointing cosmic ray density gradient existed during the 1960's, a period roughly bounded by the solar magnetic polarity reversals of 1957-58 and 1969-70. We attribute this gradient to the excess of disturbances conducted radially away from the northern hemisphere of the sun making it more difficult for galactic cosmic rays to penetrate into the northern regions of the heliosphere than into the southern. Antonucci et al., /2/ state that their analysis, using data from the neutron monitors at Climax (until 1976) and Dourbes (thereafter) also suggests a northward pointing asymmetric gradient before 1957 and after 1971. They take care, however, to point out that the statistical basis for this conclusion is not strong. Since the early 1970's, solar activity appears to have been equally divided between the two solar hemispheres, consistent with the lack of a definitive asymmetric gradient in the cosmic ray intensity. At higher energies, Swinson et al. /4/ also claim a southward pointing asymmetric gradient during the 1960's. Their method, which uses simultaneous underground muon observations in both hemispheres, cannot be extended backwards in time earlier than the commencement of underground observations in both hemispheres in 1958. Analysis of recent data is in progress.

The first indications of the existence of the perpendicular cosmic ray gradient came from ground-based cosmic ray observations, the technique used depending on the measurements being utilized. With neutron monitor measurements the annual and semi-annual intensities are used; with underground muon telescope data the amplitude of the diurnal variation must be used together with the interplanetary magnetic field vectors. Both types of analyses are complex, and relate to different regions of interplanetary space. The neutron monitor results apply to a volume, centered at the earth, of radius ≈0.05 AU, whereas the underground muon detector results apply to a volume of radius ≈0.5 AU.

Measurements of the perpendicular gradient have also been made by spacecraft, at much lower energies than those discussed here. They have mostly been made further out in the solar system, and there can be some difficulty in distinguishing between radial and perpendicular gradient effects in the case of spacecraft data.

DISCUSSION AND CONCLUSION

Many of the investigations on the perpendicular cosmic ray gradient have been made using data acquired in the 1960's. By coincidence this also is the period during which solar activity has been more consistently asymmetrical than at any time in the previous 80 years. Thus it would appear that the observed density gradient may not reflect "normal" cosmic ray conditions; i.e. the presence of excessive solar activity in the northern hemisphere of the sun may be the principal reason why a significant asymmetrical perpendicular gradient was observed. As indicated in Figure 1, the sun does not appear to have had many prolonged periods of excess solar activity in one hemisphere or the other during the past 100 years; therefore we conclude that the effects of excessive solar activity in the northern hemisphere of the sun during the 1960's may influence the existence and/or magnitude of any perpendicular cosmic ray gradients.

We note that a asymmetric perpendicular cosmic ray gradient might also result from an offset in the neutral sheet above or below the solar equatorial plane. Such an offset would itself be likely to be related to hemispheric asymmetries in solar activity.

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